CHAPTER 3

EPA/NSF ETV EQUIPMENT VERIFICATION TESTING PLAN COAGULATION AND FILTRATION FOR REMOVAL OF ARSENIC

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for evaluation of water treatment equipment for arsenic removal utilizing chemical coagulation and filtration processes. This Testing Plan is to be used as a guide in the development of Product-Specific Test Plan procedures for testing coagulation and filtration equipment, within the structure provided by the "EPA/NSF ETV Protocol for Equipment Verification Testing For Arsenic Removal: Requirements for All Studies." This Equipment Verification Testing Plan is applicable only to granular media filtration processes that rely upon chemical coagulation to effectively condition the feed water for effective filtration.

In order to participate in the equipment verification process for coagulation and filtration, the equipment Manufacturer shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of the Product-Specific Test Plan. The procedures shall generally follow those Tasks related to Verification Testing that are outlined herein, with changes and modification made for adaptations to specific equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction;
- Objectives;
- Work Plan;
- Analytical Schedule;
- Evaluation Criteria.

Each Product-Specific Test Plan shall include Tasks 1 through 6.

2.0 INTRODUCTION

Various types of water treatment equipment employing processes of coagulation and filtration are used for a wide number of applications, including removal of turbidity from surface waters; removal of pathogens such as bacteria, viruses, *Giardia* and *Cryptosporidium;* removal of algae, color, and other natural organic matter from surface waters; and removal of inorganic constituents such as arsenic. Some equipment process trains use only chemical coagulation, mixing, and granular media filtration while others employ a solids separation or clarification step between coagulation and filtration. Clarification processes may include one of the following:

- sedimentation;
- sedimentation aided by tubes or plates;
- downflow contact clarification;
- upflow contact clarification;
- dissolved air flotation (DAF).

This Equipment Verification Testing Plan is applicable to the testing of water treatment equipment utilizing a coagulation and filtration process train which may include a clarification step before filtration. Two phases of testing are discussed. The first phase is Initial Operations, which consists of a series of tests that will be used to determine the optimum chemical pretreatment scheme at a specific geographic location. The second phase is Verification Testing, which will evaluate performance of the equipment under different raw water quality conditions.

Verification Tests will be performed for relatively short time intervals during one or more periods when the source water or feed water quality is appropriate for testing the range of water quality conditions that need to be evaluated.

Several of the arsenic studies referenced in this test plan have shown that As (V) removal by coagulation and filtration is much more effective than As (III) removal. Thus a preferred approach to arsenic treatment may involve pre-oxidation to convert all arsenic to As (V) so the most effective results will be attained.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified Testing Organization that is selected by the Manufacturer. Water quality analytical work to be carried out as a part of this Verification Testing Plan shall be contracted with a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e., NSF), or the U.S. EPA

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be included in Initial Operations and of the tasks required to be included in the coagulation and filtration Verification Testing program.

4.1 Task A: Characterization of Feed Water

The objective of this recommended Initial Operations task is to obtain a chemical and physical characterization of the feed water. A brief description of the watershed that provides the feedwater shall be provided, to aid in interpretation of feedwater characterization.

4.2 Task B: Initial Tests Runs

During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the chemical dosages and other pretreatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task.

4.3 Task 1: Verification Testing Runs

Water treatment equipment shall be operated for at least 320 hours during one or more testing periods to collect data on equipment performance and water quality for purposes of performance verification.

4.4 Task 2: Feed Water and Finished Water Quality

During Verification Testing, feed water and treated water samples shall be collected, and appropriate sample analysis shall be undertaken. For example, turbidity samples are needed to determine the efficiency of surface water treatment, in addition to arsenic analyses for the evaluation of arsenic removal.

4.5 Task 3: Operating Conditions and Treatment Equipment Performance

During Verification Testing, operating conditions and performance of the water treatment equipment shall be documented. Operating conditions include pretreatment chemistry for coagulation, a listing of treatment processes used, and their operating conditions. Equipment performance includes rate of filter head loss gain, frequency and duration of filter washing, and need for cleaning of pretreatment clarifiers. The operating conditions shall include plant flow rates and chemical dosages.

4.6 Task 4: Arsenic Removal

The objective of this task is to evaluate arsenic removal during Verification Testing by measuring arsenic in the feed water and in the treated water. If the arsenic concentration naturally present in the feed water is not sufficiently high for testing, arsenic spiking is needed.

4.7 Task 5: Data Management

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the Field Testing Organization and NSF for data obtained during the Verification Testing, plus the requirement for statistical analysis of the data.

4.8 Task 6: Quality Assurance and Quality Control (QA/QC)

An important aspect of verification testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during coagulation and filtration equipment verification testing.

5.0 TESTING PERIODS

The required tasks in this test plan (Tasks 1 through 6) are designed to be carried out over one or more 320-hour periods, not including the time required for mobilization, start-up, and Initial Operations. A schedule describing the duration and initiation of each of the above tasks is provided in Table 1.

6.0 DEFINITIONS

Definitions that apply for coagulation and filtration processes and that were given in the Surface Water Treatment Rule, as published in the *Federal Register* on June 29, 1989, are:

6.1 Coagulation: A process using coagulant chemicals and mixing by which colloidal and suspended materials are destabilized and agglomerated into flocs.

6.2 Conventional filtration treatment: A series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal.

6.3 Direct filtration: A series of processes including coagulation and filtration but excluding sedimentation which results in substantial particulate removal.

6.4 Filtration: A process for removing particulate matter from water by passage through porous media.

6.5 Flocculation: A process to enhance agglomeration or collection of smaller floc particles into larger, more easily settleable particles through gentle stirring by hydraulic or mechanical means.

6.6 Sedimentation: A process for removal of solids before filtration by gravity or separation.

Other definitions include:

6.7 Dissolved air flotation: A process in which coagulated, flocculated water is introduced into the bottom of a chamber, along with recycled water containing microscopic air bubbles. The bubbles attach to the floc and rise to the water surface, carrying the floc up, while the clarified water leaves the chamber near the bottom.

6.8 Contact clarification: A process in which coagulated water is applied to a bed of coarse granular media. Flow may be downward from the top of the media bed to the bottom, or upward from the bottom of the media bed to the top. The bed of coarse media acts both as a flocculator by causing the division and recombination of flow streams of coagulated water, and as a clarifier, by trapping and removing some of the floc that forms as water flows through the bed. The coarse granular media may consist of natural mineral material or man-made materials such as plastic.

6.9 Surface Water: All water which is open to the atmosphere and subject to surface runoff. For purposes of this document, surface water includes water from surface sources such as lakes, reservoirs, canals, rivers, or streams; and it also includes ground water under the direct influence of surface water.

7.0 TASK A: CHARACTERIZATION OF FEED WATER

7.1 Introduction

The Initial Operations task is needed to determine if the chemical, biological and physical characteristics of the feed water are appropriate for the water treatment equipment to be tested.

7.2 Objectives

The objective of this task is to obtain a complete chemical, biological, and physical characterization of the source water or the feed water that will be entering the treatment system being tested.

7.3 Work Plan

This task can be accomplished by using analytical measurements obtained from third party sources (i.e. United States Geological Survey (USGS), U.S. EPA, State Laboratories, Municipal Laboratories). The specific parameters needed to characterize the water will depend on the equipment being tested but information on the following characteristics should be compiled:

- Water temperature, pH, turbidity, and arsenic concentration and species
- Total alkalinity, calcium hardness, iron, manganese, sulfate, silica and fluoride
- Algae, color, and total organic carbon (TOC)

Sufficient information should be obtained to illustrate the variations expected to occur in these parameters that will be measured during Verification Testing for a typical annual cycle for the water source. This information will be compiled and shared with NSF so NSF and the Field Testing Organization can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. Failure to adequately characterize the feed water (source water) could result in testing at a site later deemed inappropriate, so the initial characterization will be important to the success of the testing program. Hering et al. (1997) have shown that under certain conditions, source water composition can influence arsenic removal by coagulation and filtration, so a good understanding of source water composition could be important to the outcome of Verification Testing.

A brief description of the watershed that provides the feedwater shall be provided to aid in interpretation of feedwater characterization. The watershed description should include:

- approximate size
- topography (i.e. flat, gently rolling, hilly, mountainous)
- types of human activities that take place (i.e. mining, manufacturing, cities or towns, farming)
- potential sources of pollution influencing water quality, especially potential sources for arsenic discharge
- nature of the water source, such as stream, river, lake, wells, or man-made reservoir.

7.4 Analytical Schedule

In many cases, sufficient water quality data may already exist in the determination of the suitability of a source water for use as feedwater in a coagulation and filtration Verification Testing program.

7.5 Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of performance objectives. The feed water should challenge the capabilities of the equipment but should not be beyond the range of water quality suitable for treatment for the equipment in question. For example, if the Manufacturer's equipment is only capable of treating a maximum arsenic influent concentration of 200 μg/L, it would not be appropriate to test a feedwater containing an influent arsenic concentration of 300 μg/L.

8.0 TASK B: INITIAL TEST RUNS

8.1 Introduction

During Initial Operations, a Manufacturer may want to evaluate equipment operation and determine the chemical dosages and other pretreatment conditions that result in effective treatment of the feed water. This is a recommended Initial Operations task. An NSF field inspection of equipment operations and sampling and field analysis procedures may be carried out during the initial test runs.

8.2 Objectives

The objective of the test runs is to determine the proper chemical pretreatment scheme for treatment of the feedwater during Verification Testing. The chemical pretreatment requirements may be different for feedwaters from different test sites, different sources, or for the feedwater from the same site during testing periods when water quality has changed from the quality encountered during an earlier testing period. Therefore, conducting initial test runs is strongly recommended.

8.3 Work Plan

Before runs are made in which coagulant is used, the equipment shall be operated with uncoagulated feed water (spiked with arsenic if necessary) for one 24-hour run, and samples shall be collected from the feed water, clarifier effluent, and the filter effluent at 6, 12, 18, and 24 hours of operation to determine if arsenic losses occur through the system. Even though this test run is made during the Initial Operations, the data shall be presented in the Verification Testing report.

Conducting jar tests is often a cost effective means of developing data on coagulant chemical dosages and pH that give effective coagulation. The use of jar tests is recommended before filtration testing is initiated. The American Water Works Association's Manual M37 (1992), contains a chapter that describes procedures for using jar tests to optimize coagulation. Tests conducted for the effectiveness of both alum and iron as inorganic coagulants may be appropriate. The effect of polymer addition as a coagulant aid, and the effect of pH adjustment (acid or base addition) could also be examined through jar tests. Extensive bench-scale coagulation studies of arsenic removal have been performed previously at different test sites to determine arsenic removal, as demonstrated by various researchers (Sorg and Logsdon, 1978; Cheng, *et al*., 1994).

After jar tests have identified effective treatment conditions, several test runs may be needed to further refine appropriate chemical pretreatment conditions. At the end of these tests, an effective chemical pretreatment scheme should have been defined. During initial operations the filters should be operated for a period of 24 hours, or for filter run times as long as those anticipated during verification testing. The use of bench-scale tests followed by pilot-scale coagulation tests, using alum and ferric chloride, is documented in a study performed by Cheng, *et al*. (1994), and may be used as a guide for performing this phase of testing.

Filters will be operated until either terminal headloss is reached or effluent turbidity increases above 0.5 NTU or a value set by the Manufacturer (but no higher than 0.5 NTU).

8.4 Analytical Schedule

Because these runs are being conducted to define operating conditions for verification testing, a strictly defined schedule for sampling and analysis may not need to be followed. Adhering to the schedule for sampling and analysis to be followed during verification testing would be wise, however, so the operator can gain familiarity with the time requirements that will be applicable later on in the test program. Also, during the Initial Operations phase, NSF may conduct an initial on-site inspection of field operations and sampling activities. The sampling and analysis schedule for Verification Testing shall be followed during the on-site inspection.

8.5 Evaluation Criteria

The Manufacturer should evaluate the data produced during the Initial Operations to determine if the water treatment equipment performed so as to meet or exceed expectations based on the statement of performance objectives for arsenic removal. If the performance was not as good as the statement of performance objectives, the Manufacturer may wish to conduct more Initial Operations or to cancel the testing program.

9.0 TASK 1: VERIFICATION TESTING RUNS

9.1 Introduction

Drinking water treatment equipment employing coagulation and filtration shall be operated for Verification Testing purposes, with the approach to coagulation based on the results of the Initial Operations testing.

9.2 Experimental Objectives

The objective of this task is to operate the treatment equipment provided by the Manufacturer and to assess its ability to meet the water quality goals and any other performance characteristics specified by the Manufacturer in the statement of performance objectives.

9.3 Work Plan

9.3.1 Verification Testing Runs

The Verification Testing Runs in this task consist of continued evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations. To obtain a perspective on the influence of feed water quality on the overall performance of the equipment, one or more Verification Testing periods, each lasting for a minimum of 320 hours (the equivalent of 13 full days plus one 8-hour shift), are anticipated for evaluating the performance of a treatment system. During each of these testing periods, Tasks 1 through 5 shall be conducted simultaneously.

Operation under a variety of water quality conditions is recommended because of the differences in water quality that occur over time in many source waters. For coagulation and filtration treatment equipment, factors that can influence treatment performance include:

- cold water, encountered in winter or at high altitudes in mountainous regions
- high turbidity, often occurring in spring, encountered in rivers carrying a high sediment load or in surface waters during periods of high runoff resulting from heavy rains or snowmelt
- algae, which may bloom on a seasonal basis such as in summer or fall
- natural organic matter (NOM), which may be higher in some waters in the fall
- pH, alkalinity, and hardness, which may vary over time
- sulfate can influence arsenic removal (Hering et al. 1997)

It is highly unlikely that all of the above problems would occur in a surface water during a single test period, and this results in the recommendation for testing during different times or at different locations. Testing a water which has little change in quality over time could result in acceptance of equipment for use only in water having a narrow range of water quality.

9.3.2 Routine Equipment Operation

If the water treatment equipment is being used for production of potable water and treats a water that naturally contains concentrations of arsenic appropriate for Verification Testing, so that arsenic spiking is not needed, routine operation for water production is anticipated in the time intervals between verification runs. The operating and water quality data collected and furnished to the Safe Drinking Water Act (SDWA) primacy agency during these times shall also be supplied to the NSF-qualified Testing Organization.

9.4 Schedule

To meet the goals of the Verification Testing, the following conditions shall be met:

- Water treatment equipment shall be operated continuously for a minimum of 320 hours (the equivalent of 13 full days plus one 8-hour work shift)
- During this time, coagulation and filtration treatment equipment shall be operated continuously from start-up until turbidity breakthrough or terminal head loss is attained.
- Interruptions in filtration shall occur only as needed for backwashing of the filters or contact clarification pretreatment unit.
- Filter runs shall not be stopped before turbidity breakthrough or terminal head loss is achieved, with the exception of equipment failure or power interruption.
- The duration of each filter run and the number of gallons of water produced per square foot of filter area shall be recorded in the operational results.
- During routine equipment operation, the water treatment equipment should be operated to meet the system demands and water quality requirements.

9.5 Evaluation Criteria

The goal of this task is to operate the equipment for the 320 hour period, including time for filter backwashing and other necessary operating activities, during Verification Testing. Data shall be provided to substantiate the operation for 320 hours or more.

10.0 TASK 2: FEED WATER AND FINISHED WATER QUALITY

10.1 Introduction

Water quality data shall be collected for the feedwater and filtered water as shown in Table 2, during Verification Testing. At a minimum, the required sampling schedule shown in Table 2 shall be observed by the Field Testing Organization. Water quality goals and target removal goals for the water treatment equipment shall be recorded in the Product-Specific Test Plan in the statement of objectives.

10.2 Experimental Objectives

A list of the minimum number of water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 3. The actual water quality parameters selected for testing shall be stipulated in the Product-Specific Test Plan procedures and shall include all those necessary to permit verification of the statement of performance objectives.

10.3 Work Plan

The Field Testing Organization will be responsible for establishing the equipment operating parameters on the basis of the Initial Operations testing. The filter shall be operated continuously until turbidity breakthrough or terminal headloss is attained, at which time it shall be backwashed.

Some of the water quality parameters described in this task will be measured on-site by the NSF-qualified Testing Organization (refer to Table 3). Analysis of the remaining water quality parameters will be performed by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e., NSF), or the U.S. EPA. The methods to be used for measurement of water quality parameters in the field are described in Table 3. The analytical methods utilized in this study for on-site monitoring of feedwater and filtered water qualities are discussed in Task 6, Quality Assurance/Quality Control (QA/QC). Where appropriate, the *Standard Methods* reference numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

10.3.1 Water Quality Sample Collection

Water quality data shall be collected during each period of filtration testing, as noted in this section. Additional sampling and data collection may be performed at the discretion of the Manufacturer. Sample collection frequency and protocol shall be defined in the Product-Specific Test Plan.

In the case of water quality samples that will be shipped to the State or EPA-accredited analytical laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the State or EPA-accredited analytical laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory.

10.4 Analytical Schedule

During Verification Testing for coagulation and filtration treatment equipment, the feed water (raw water) quality, filtered water quality, (and if applicable, the clarified water quality) shall be characterized by measurement of the following water quality parameters. For pH samples, the treated water pH must be the pH of the coagulated water because coagulation pH can have a strong influence on arsenic removal. If any pH adjustment is made after coagulation, this also must be noted. Water quality samples, whether designated for collection at maximum intervals of once per day or once per week shall be obtained during each arsenic challenge test that involves distinct treatment conditions, even if this increases the water quality sample collection frequency to greater than once per week. Additionally, the sludge generated from process should be analyzed for arsenic, iron, and manganese.

- temperature (daily)
- pH (8-hour intervals and in conjunction with arsenic sample collection)
- total alkalinity (daily)
- hardness (weekly or once during each set of treatment conditions for which arsenic sampling is done)
- total organic carbon (weekly or once during each set of treatment conditions for which arsenic sampling is done)
- UV_{254} absorbance (weekly or once during each set of treatment conditions for which arsenic sampling is done)
- turbidity (daily at bench to check continuous turbidimeters)
- aluminum (weekly if an aluminum salt coagulant is used or once during each set of treatment conditions for which arsenic sampling is done and alum is the coagulant chemical)
- iron (weekly or once during each set of treatment conditions for which arsenic sampling is done and iron is the coagulant chemical)
- manganese (weekly or once during each set of treatment conditions for which arsenic sampling is done if above 0.05 mg/L in feed water)
- algae, number and species (weekly or once during each set of treatment conditions for which arsenic sampling is done)
- true color (weekly or once during each set of treatment conditions for which arsenic sampling is done)
- sulfate (weekly)
- dissolved oxygen concentration in feed water (daily)
- dosage of pre-oxidation chemical and residual concentration after filter (if a preoxidation chemical was used) (only in Task 4, every 6 hours to coincide with arsenic sampling)
- arsenic (see Task 4)

The above water quality parameters are listed to provide verification report readers with background data on the quality of the feed water being treated and the quality of the filtered water. These data are to be collected to enhance the usefulness of the Verification Testing data to a wide range of verification report readers. Data on feed water need to be obtained because of the possibility that feed water composition could influence arsenic removal performance for some operating variables, including coagulation pH, coagulant chemical used, and valence state of the arsenic.

10.5 Evaluation Criteria

For systems that treat surface water, performance shall be evaluated in the context of the Manufacturer's statement of performance objectives.

Turbidity results for systems treating surface waters shall be analyzed to determine the percentage of turbidity data in the range of 0.10 NTU or lower, the percentage in the range of 0.11 NTU to 0.20 NTU, the percentage in the range between 0.21 NTU and 0.34 NTU, the percentage between 0.35 NTU and 0.54 NTU, and the percentage that equaled or exceeded 0.55 NTU. The percentage of filtered water turbidity results that exceed 1.0 NTU shall also be noted. In addition the frequency of occurrence in which the filter was placed into service after backwashing and subsequently produced filtered water turbidity exceeding 0.5 NTU after a four hour ripening period (i.e. the turbidity did not fall to below 0.5 NTU within four hours of starting the filter) shall be noted. The time intervals used for determining turbidity values shall be the same for all data analyzed, and because continuous turbidimeters are to be used to collect turbidity data, the intervals shall be between 5 and 15 minutes.

For systems treating ground water, the equipment will evaluated in this phase with respect to achieving water quality and removal goals as specified by the statement of performance objectives.

11.0 TASK 3: OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE

11.1 Introduction

Operating conditions shall be documented during each day of Verification Testing. This shall include descriptions of chemicals used for coagulation, pretreatment chemistry for coagulation, treatment processes used, and operating conditions. In addition, the performance of the water treatment equipment shall be documented, including rate of filter head loss gain, frequency and duration of filter backwashing, and need for cleaning of pretreatment clarifiers.

11.2 Objectives

The objective of this task is to accurately and fully document the operating conditions applied during treatment and the equipment performance. This task is intended to result in operational data describing the operation of the equipment which can be used to develop cost estimates.

11.3 Work Plan

A description of the testing equipment shall include:

- Complete description of each process, with data on volume and detention time of each process basin at rated flow.

- Data on each layer of the filtering and support material, including:
  - Depth
  - Material type

  - Effective size
  - - Uniformity coefficient
- Location of each chemical or polymer addition point.

During Verification Testing, the following items shall be monitored, collected, recorded, or analyzed:

- Treatment equipment operating parameters for both pretreatment and filtration, including:
  - Pretreatment chemistry
  - Mixing and flocculation intensities
  - Operating parameters for clarification ahead of filtration; rate of flow; and filtration rate
  - Process detention times
- Filter head loss and backwashing data.
- Chemical dosages for all chemicals used. In addition, the supplier and manufacturer of the coagulant chemical, the strength of solution for liquid coagulants, the specific gravity for liquid coagulants, and the chemical formula and percentage of impurities for dry coagulants shall be documented and included in the report of the testing.
- Electrical energy consumed by the treatment equipment or aggregate horsepower of all motors supplied with the equipment for estimating the maximum power consumption during operation.

11.4 Schedule

Table 4 presents the schedule for observing and recording coagulation and filtration equipment operating and performance data.

11.5 Evaluation Criteria

Where applicable, the data developed from this task will be compared to statements of performance objectives with respect to filter head loss, frequency and duration of filter backwashing, and the need for pretreatment clarifier cleaning.

If no relevant statement of performance objectives exists, for each set of conditions employed in arsenic challenge testing, the results of operating and performance data shall be tabulated for inclusion in the Verification Report, and shall include:

- average rate of flow for equipment, gallons/day;
- average filtration rate, g.p.m./sf;
- average run length, hours;
- average daily chemical usage and cost for treatment chemicals;
- average daily energy cost;
- average daily wash water production, and;
- average daily sludge or floated solids production

12.0 TASK 4: ARSENIC REMOVAL

12.1 Introduction

Arsenic removal may be a primary purpose of coagulation and filtration of some surface and ground waters in the future. Consequently, the effectiveness of coagulation and filtration treatment processes for arsenic removal will be evaluated in this task. Additionally, turbidity removal is also needed to ensure that water quality goals are met when treating surface waters. Therefore, assessment of treatment efficacy will be made on the basis of turbidity measurements in Task 3 and arsenic removal for surface water treatment and on the basis of arsenic removal for ground water treatment in this task.

12.2 Experimental Objectives

The objective of this task is to evaluate arsenic removal during Verification Testing by measuring arsenic naturally present in the feed water or by spiking the feed water with arsenic in the treated water.

12.3 Work Plan

Task 4 shall be carried out during the Verification Testing runs conducted in Task 1. The treatment equipment shall be operated using the chemical pretreatment conditions that provide effective clarification (if used) and filtration.

Evaluation of arsenic removal shall be performed by analyzing arsenic in the feed and filtered waters. If arsenic spike testing is required, the appropriate arsenic species (either arsenate (V) or arsenite (III)) will be added to the feedwater.

A minimum of 48 hours of operation involving collection of 11 or more arsenic samples shall be conducted to provide statistically verifiable arsenic removal data for each condition of coagulant chemical type and dosage, coagulation pH, feed water arsenic species, and feed water arsenic concentration tested.

12.3.1 Background Arsenic Levels

If sufficient arsenic concentration is naturally present in the feed water to meet the Manufacturers' stated operating range for arsenic removal, the treatment equipment shall be operated as usual in Verification Testing runs, and sampling shall be done as stipulated in the Analytical Schedule.

12.3.2 Spiked Arsenic

Spiked arsenic shall be used in concentrations sufficient to permit the most-stressed operations for the Manufacturers' equipment, following the recommended guidelines:

- Arsenic spiking shall begin at start-up of the treatment equipment.
- Arsenic feed solution will be prepared by diluting the arsenic into dilution water that is distilled or deionized and oxidant free.

- To spike arsenic (III), use commercially-prepared arsenic trioxide. (In cold water, at 2^{o}C, the solubility of this chemical is about 1.2 g/100 g water.)
- To spike arsenic (V), use commercially-prepared arsenic pentoxide.
- Feed reservoir for the arsenic spike solution shall be made of chemically inert material (i.e., not reactive or adsorbable to the arsenic).
- The reservoir will be mixed continuously throughout the experiment.
- The arsenic spike solution will be fed using an adjustable rate chemical feed pump.
- Use an in-line static mixer to mix this solution into the feedwater.
- Arsenic samples of at least 250 mL shall be collected in bottles prepared for holding such samples.

If testing with Arsenic (III) is contemplated, Manufacturers and Field Testing Organizations need to be aware of potential difficulties in preventing conversion of As (III) to As (V) as the spiking solution is held in its storage container. Further conversion to the higher valence state could occur during passage of spiked water through the equipment. Several of the arsenic studies referenced in this test plan have shown that As (V) removal by coagulation and filtration is much more effective than As (III) removal. Thus a preferred approach to arsenic treatment may involve pre-oxidation to convert all arsenic to As (V) so the most effective results will be attained. If pre-oxidation is done, the conditions need to be documented.

12.4 Analytical Schedule

Turbidity in feed water samples may be measured on a batch or a continuous basis. For facilities treating surface waters, if batch measurements are used, they shall be performed every six hours during each working day in the Verification Testing. Filtered water analysis shall be conducted using continuous flow turbidimeters equipped with recording capability so data can be collected on a 24-hour-per-day basis during Verification Testing.

Chemistry samples shall be collected from the plant influent (feed water after spiking, if arsenic is spiked), clarifier effluent if a clarification step is employed ahead of filtration, and the filter effluent. Samples shall not be collected until the treatment plant has been in operation for a total of three (3) theoretical detention times (the theoretical detention time is the volume of water held in the treatment equipment, divided by the rate of flow) as measured through the pretreatment process up to the filter. For arsenic sampling purposes, the time of operation when three pretreatment detention times have elapsed shall be considered time zero. Arsenic samples shall be collected at time zero and at 1, 3, and 6 hours past time zero. Thereafter arsenic samples shall be collected once every 6 hours thereafter until the end of the filter run or until the filter run has lasted 48 hours from time zero. This would result in collection of 11 sets of arsenic samples in a 48-hour filter run. Because four sets of arsenic samples are to be collected during the first 6 hours of a filter run, conducting more than one filter run during the 48 hour period required for a given set of treatment conditions would result in collection of more than 11 sets of arsenic samples. During each sampling event, one 250-mL sample will be collected at each sampling location. The exact time of sampling will be recorded so turbidity measurements can be determined at the time of sampling. When Task 4 is carried out, if pre-oxidation is done, the pre-oxidant dosage and the pre-oxidant residual after filtration are to be determined at time zero and at 6-hour intervals through the 48-hour time period required for this task.

The Testing Organization shall then submit collected water samples to a state or EPA-accredited analytical laboratory for arsenic testing. The laboratory shall have a minimum detection limit for arsenic of 1 μg/L.

12.5 Evaluation Criteria

Performance evaluation shall be conducted in a number of ways, depending on the types of data collected during testing. Performance of coagulation and filtration equipment shall be evaluated in the context of the Manufacturer's statement of performance objectives with respect to arsenic removal and the filtered-water turbidity goals if surface water was treated. For arsenic removal by coagulation and filtration, the following information shall be provided:

- valence of the arsenic being treated by coagulation and filtration, i.e. As (III) or As (V);
- pH of coagulated water;
- coagulant chemical used, and;
- coagulant dosage

An example of a statement of performance objectives for arsenic removal might be, "Coagulation and filtration in the pH range of 7.0 to 8.0 can reduce arsenate [Arsenic (V)] concentration by 90 percent when the initial arsenic concentration is in the range of 20 to 100 μg/L and a 30 mg/L dose of ferric sulfate is used for coagulation." To provide data to verify such a performance statement, testing would have to be done at pH 7.0 for feed water with arsenic at 20 μg/L and with arsenic at 100 μg/L. Testing at both arsenic concentrations also would be required at pH 8.0. If a statement of performance objectives specifies the type of coagulant and the dosage that is effective, both the coagulant type and dosage would also be required to be used for all conditions tested.

13.0 TASK 5: DATA MANAGEMENT

13.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software and manual recording of operational parameters for the water treatment equipment on a daily basis.

13.2 Experimental Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Field Testing Organization provides sufficient and reliable operational data for verification purposes. A second objective is to develop a statistical analysis of the data, as described in "Protocol for Equipment Verification Testing for Arsenic Removal."

13.3 Work Plan

13.3.1 Data Handling

The following protocol has been developed for data handling and data verification by the Field Testing Organization. Where possible, a Supervisory Control and Data Acquisition

(SCADA) system should be used for automatic entry of testing data into computer databases.

- Specific parcels of the computer databases for operational and water quality parameters should be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file.
- Specific database parcels will be identified based on discrete time spans and monitoring parameters.
- The data will be manipulated into a convenient framework to allow analysis of coagulation and filtration equipment operation in a spreadsheet form.
- Backup of the computer databases to diskette should be performed on a monthly basis at a minimum.

In the case when a SCADA system is not available,

- Field testing operators will record data and calculations by hand in laboratory notebooks. (Daily measurements will be recorded on specially-prepared data log sheets as appropriate.)
- Laboratory notebook will contain carbon copies of each page (to ease referencing the original data and offer protection of the original record of results.)
- Original notebooks will be stored on-site; the carbon copy sheets will be forwarded to the project engineer of the Field Testing Organization at least once per week.
- Operating logs shall include a description of the process equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

Spreadsheets

- The data for the project will recorded in custom-designed spreadsheets.
- The spreadsheets will be capable of storing and manipulating each monitored water quality and operational parameter from each task, sampling location, and sampling time.
- All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheet.
- Data entry will be conducted on-site by the designated field testing operators, with all recorded calculations checked at this time.
- Following data entry, the spreadsheet will be printed out and the printout will be checked against the handwritten data sheet.
- Any corrections will be noted on the hard-copies and corrected on the screen, and a corrected version of the spreadsheet will be printed out.
- Each step of the verification process will be initialed by the field testing operator or engineer performing the entry or verification step.

Data Tracking

- Each experiment (e.g., each filtration test run) will be assigned a run number which will then be linked to the data from that experiment through each data entry and analysis step.
- Data will be tracked by use of the same system of run numbers as samples are collected and sent to State or EPA-accredited analytical laboratories.
- Data from the analytical laboratories will be received and reviewed by the Field Testing Organization.
- These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

13.3.2 Statistical Analysis

Arsenic data developed from grab samples collected during filter runs according to the Analytical Schedule in Task 4 of this Test Plan shall be analyzed for statistical uncertainty. The Field Testing Organization shall calculate 95% confidence intervals for the arsenic data obtained during Verification Testing as described in "Protocol for Equipment Verification Testing for Arsenic Removal." A separate statistical analysis shall be carried out for each testing condition for which the required 11 or more sets of arsenic samples were collected and analyzed.

The statistics developed will be helpful in demonstrating the degree of reliability with which the water treatment equipment can attain quality goals under the treatment conditions tested. The results of the statistical analysis also shall be used to determine if the performance of the equipment was equal to or better than that given in the statement of performance objectives.

14.0 TASK 6: QA/QC

14.1 Introduction

Quality assurance and quality control of the operation of the coagulation and filtration equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 Work Plan

Equipment flow rates and associated signals should be documented and recorded on a routine basis. A routine daily walk-through during testing will verify that each piece of equipment or instrumentation is operating properly. Particular care will be taken to confirm the water and chemicals flow rates to ensure that the chemical feed concentrations are correct. In-line monitoring equipment, such as flow meters and turbidimeters, will be checked to confirm that the readout matches with the actual measurement (i.e. flow rate, turbidity) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

14.3.1 Daily QA/QC Verifications

- Chemical feed pump flow rates (verified volumetrically over a specific period of time)
- In-line turbidimeters flow rates (verified volumetrically over a specific period of time)
- In-line turbidimeters readings checked against a properly calibrated bench model.

14.3.2 QA/QC Verifications Performed Every Two Weeks

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

14.3.3 QA/QC Verifications for Each Test Period

- In-line turbidimeters (clean out reservoirs and recalibrate)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)
-

14.4 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw water and treated water quality are described in the section below. In-line equipment is recommended for its ease of operation and because it limits the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. In-line equipment is recommended for measurement of turbidity and for particle counting for feed water and is required for measurement of turbidity and for particle counting for filtered water.

14.4.1 pH

- pH analysis shall be performed according to Standard Method 4500-H^+ or EPA Method 150.1/150.2.
- A three-point calibration of the pH meter shall be performed once per day when the instrument is in use.
- Certified pH buffers in the expected range shall be used.

- The pH probe shall be stored in the appropriate solution defined in the instrument manual.
- Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, pH measurement in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

14.4.2 Turbidity

Turbidity analyses shall be performed according to *Standard Methods* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters shall be used for measurement of turbidity in the filtrate waters, and either an in-line or bench-top may be used for measurement of the feedwater.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring equipment.

14.4.2.1 Bench-Top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples that cause the vial to fog preventing accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

14.4.2.2 In-Line Turbidimeters. In-line turbidimeters are required for filtered water monitoring during verification testing and must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable.

Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow rate should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

14.4.3 Temperature

Readings for temperature shall be conducted in accordance with Standard Method 2550. Raw water temperatures should be obtained at least once daily. The thermometer shall have a scale marked for every 0.1°C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1°C to +51°C, subdivided in 0.1° increments, would be appropriate for this work.)

14.4.4 Color

True color shall be measured with a spectrophotometer at 455 nm, using a Hach Company adaptation of the *Standard Methods* 2120 procedure. Samples should be collected in clean plastic or glass bottles and analyzed as soon after collection as possible. If samples can not be analyzed immediately they should be stored at 4°C for up to 24 hours, and then warmed to room temperature before analysis. The filtration system described in *Standard Methods* 2120 C should be used, and results should be expressed in terms of PtCo color units.

14.5 Chemical and Biological Samples Shipped Off-Site for Analyses 14.5.1 Organic Parameter: Total Organic Carbon and UV_{254} Absorbance

Samples for analysis of TOC and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA- accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held, and shipped in accordance with *Standard Method* 5010B. Storage time before analysis shall be minimized, according to *Standard Methods*.

14.5.2 Inorganic Samples

Inorganic chemical samples, including arsenic, alkalinity, hardness, aluminum, iron, and manganese, shall be collected, preserved, shipped, and held in accordance with *Standard Method* 3010B, paying particular attention to the sources of contamination as outlined in *Standard Methods* 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C during shipment. Samples shall be processed for analysis by a state-certified or third party- or EPA- accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

14.5.3 Algae

Algae samples shall be preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately 4°C, and held at that temperature range until counted.

15.0 OPERATIONS & MAINTENANCE (O&M)

The Field Testing Organization shall obtain the Manufacturer-supplied O&M manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for equipment employing coagulation and filtration.

15.1 Maintenance

The Manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- valves
- chemical feeders
- mixers
- motors
- instruments, such as continuous pH monitors or turbidimeters
- water meters, if provided

The Manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- tanks and basins
- in-line static mixers
- filter vessels

15.2 Operation

The Manufacturer should provide readily understood recommendations for procedures related to proper operation of the equipment. Among the operating aspects that should be discussed are:

Chemical feeders:

- calibration check
- settings and adjustments -- how they should be made
- dilution of chemicals and polymers -- proper procedures

Mixers and flocculators:

- purpose
- changing intensity (RPM), if available

Filtration:

- control of filtration rate
- observation and measurement of head loss during filter run

Filter backwashing:

- end of filter run
- use of auxiliary water scour (surface wash) or air scour
- start of backwash
- appropriate backwash rates
- conclusion of filter backwashing
- return of filter to service

Monitoring and observing operation:

- observation of floc
- pretreated water turbidity, if appropriate
- filtered water turbidity
- filter head loss
- what to do if turbidity breakthrough occurs
- measuring and controlling pH of coagulated water

Coagulant dose selection:
Strongly recommend that Manufacturer include a copy of AWWA Manual M37, "Operational Control of Coagulation and Filtration Processes" with each coagulation and filtration package plant, as an AWWA committee of experts has prepared an excellent manual that would be very helpful to plant operators.

The Manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- no raw water (feed water) flow to plant
- can't control rate of flow of water through equipment
- no chemical feed
- calibration and maintenance of on-line pH monitoring instruments, problems of erratic pH or drifting pH readings
- mixer or flocculator will not operate (won't rotate)
- filter can't be backwashed or backwash rate of flow can't change
- no reading on turbidimeter or streaming current monitor
- automatic operation (if provided) not functioning
- filtered water turbidity too high
- filter head loss builds up excessively rapidly
- no head loss readings
- valve stuck or won't operate
- no electric power

The following are recommendations regarding operability aspects of equipment employing coagulation and filtration. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of equipment testing when the testing is done under the ETV Program.

During Verification Testing and during compilation of historical equipment operating data, attention shall be given to equipment operability aspects. Among the factors that should be considered are:

- fluctuation of chemical feed rate from desired value -- the time interval at which re-setting

is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
- presence of devices to aid the operator with chemical dosage selection:
  - streaming current monitor provided?
  - influent and filtered water continuous turbidimeters provided?
  - on-line pH meter provided?
- can backwash be done automatically?
- if automatic backwash provided, could it be initiated by:
  - reaching a set value for head loss?
  - reaching a set value for filtered water turbidity?
- does remote notification to operator occur when backwash happens?
- can operator observe filter backwash?
- how can plant operator check on condition and depth of filter media?
- can flocculation energy be varied?
- does plant have multiple feed points for chemicals:
  - for pH adjustment?
  - for coagulant chemical feed?
  - for polymer feed?
- is head loss measurement provided?
- is rate of flow of raw water measured?
- is chemical feed paced with raw water flow?
- can coagulation pH be maintained automatically if raw water flow changes?
- is backwash rate of flow measured and variable?
- is backwash duration (time) variable?

Does the equipment have sensors or monitoring equipment that can detect an equipment malfunction, unsatisfactory treated water quality, or operating conditions that exceed allowable limits, and if so, during such situations can the equipment be automatically shut down? Upon automatic shut-down, can a means of operator notification be provided, if the operator is not present on the site where the equipment is located?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Task 3: Operating Conditions and Treatment Equipment Performance, in this Test Plan.

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Table 1. Generic Schedule for Verification Testing		
Test Period	Initial Operations Estimated Time (wks)	Verification Testing Required Time (hrs)
1, required	1 - 6	320
2, optional	1 - 3	320
3, optional	1 - 3	320
4, optional	1 - 3	320

Table 2. Water Quality Sampling and Measurement Schedule	
Parameter	**Minimum Frequency**
Temperature	Daily
pH*	Once per 8-hours during runs with no arsenic sampling. Measure pH of coagulated water each time arsenic samples are collected.
Total alkalinity	Daily
Hardness	Weekly**
Total organic carbon	Weekly**
UV254 absorbance	Weekly**
Turbidity	Daily at bench to check continuous turbidimeters
Aluminum	Weekly**
Iron	Weekly**
Manganese	Weekly** if present in concentration of 0.05 mg/L or greater
Total suspended solids in backwash water	See Task 4
Arsenic	See Task 4
Sulfate	Weekly
Dissolved Oxygen in feedwater	Daily
Algae, number and species	Weekly or once during each set of treatment conditions for which arsenic sampling is done
True color	Weekly**
Dosage of pre-oxidation chemical and pre-oxidation chemical residual in filtered water	Only in Task 4, every 6 hours beginning at time zero
Sampling points: feed water, clarified water (if applicable) and filtered water. During arsenic challenge testing, collection of weekly and daily samples shall be coordinated with arsenic sampling so other water quality data can be related to arsenic results. *For pH samples, filtered water pH values are valid only if no pH adjusting chemicals are added after coagulation. The pH of filtered water is intended to represent the pH of coagulation. **For each testing condition employed during an arsenic challenge test, at least one set of the above samples shall be collected so feed water and treated water can be characterized for each testing condition. This may change the frequency to more often than weekly.	

Table 3. Analytical Methods			
Parameter	**Facility**	***Standard Methods*1 number or Other Method Reference**	***EPA Method2***
Temperature	*On-Site*	*2550 B*	
pH	*On-Site*	*4500-H+ B*	*150.1 / 150.2*
Total alkalinity	*Lab*	*2320 B*	
Total Hardness	*Lab*	*2340 C*	
Total organic carbon	*Lab*	*5310 C*	
UV_{254} absorbance	*Lab*	*5910 B*	
Turbidity	*On-Site*	*2130 B / Method 2*	*180.1*
Aluminum	*Lab*	*3111 D / 3113 B / 3120 B*	*200.7 / 200.8 / 200.9*
Iron	*Lab*	*3111 D / 3113 B / 3120 B*	*200.7 / 200.8 / 200.9*
Manganese	*Lab*	*3111 D / 3113 B / 3120 B*	*200.7 / 200.8 / 200.9*
Suspended solids in backwash water	*Lab*	*2450 D*	
Algae, number and species	*Lab*	*10200 and 10900*	
Sulfate	*Lab*	*4500-SO_4 B, C, or D*	*300.0, 375.2*
Dissolved Oxygen	*On-Site*	*4500-O C or G*	
True Color	*On-Site*	*2120 B (Hach Company modification of SM 2120 measured in spectrophotometer at 455 nm)*	
Arsenic concentration and species	*Lab*	*3113 B / 3114 B / 3120 B*	*200.7 / 200.8 / 200.9*
Pre-oxidants: *Ozone Residual* *Chlorine* *Chlorine Dioxide* *Potassium Permanganate (if used to oxidize Arsenic III)*	 *On-Site* *On-Site* *On-Site* *Lab*	 *4500-O_3 B* *4500-Cl* *4500-ClO_2* *3111*	

Notes:

1) Standard Methods Source: 20th Edition of Standard Methods for the Examination of Water and Wastewater, 1999, American Water Works Association.

2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Table 4. Equipment Operating Data	
Operating Data	***Action***
Chemicals Used	*Record on a daily basis: type; supplier; commercial strength (e.g. as percent Fe or Al, specific gravity of liquid coagulants or percent purity and chemical formula of dry coagulants) and; dilution for stock solution to be fed (if diluted).*
Chemical Type, Feed Volume and Dosage	*Check and record each 2 hours.* *Refill as needed, note volumes and times of refill. Maintain all calculations on coagulant chemical solution preparation and all data on coagulant chemicals as purchased from supplier or chemical manufacturer Calculate the chemical dosage for each filter run in which arsenic challenge testing was carried out.*
RPM of Rapid Mix and Flocculator	*Check once/day and record*
Feedwater Flow and Filter Flow	*Check and record each two hours* *Adjust when flow >10% above or below goal* *Record flows before and after adjustment.*
Filter Head Loss	*Record initial clean bed total head loss at start of filter run* *Record total head loss every two hours.* *Record terminal head loss at end of filter run.*
Filtered Water Production	*Record gallons of water produced per square foot of filter area, for each filter run. [This figure is the product of filtration rate (gpm/sf) and length of filter run in minutes for a filter run performed at constant rate.]*
Filter Backwash	*Record time and duration of each filter backwashing.* *Record water volume used to wash filter.*
Sludge Production	*If sludge is drawn off, record volume of sludge.*
Suspended solids in washwater	*Determine suspended solids in washwater for each set of arsenic removal testing conditions.*
Clarifier/flocculator or other similar process ahead of filter	*If clarifier/flocculator is backwashed separately from backwashing of filter, record the time of every backwash for this process, and volume of water used.*
DAF flotate removal	*Record frequency of flotate removal action each day.*

Table 4. Equipment Operating Data (continued)	
Operating Data	***Action***
DAF recycle flow	*Record recycle water flow rate each 8 hours.*
DAF saturator pressure	*Record DAF saturator vessel pressure each 8 hours.*
Electric Power	*Record meter reading once per day*
Hours operated per day	*Record in log book at end of day or at beginning of first shift on the following work day.*
All parameters will be checked only during times when the equipment is staffed.	